Understanding the Sources of X-ray Emission from Hot Stars

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Implications of X-ray properties of Hot Stars

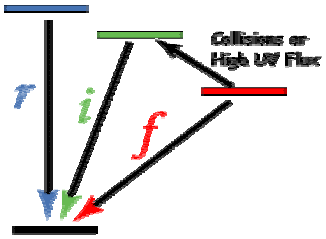
→ X-ray emitting gas (mostly $T < 10^7$ K) is distributed *throughout* the winds.

→ The winds probably contain many individual structures such as *Shock Fragments*, and clumps with *Bow Shocks*.

→ *Wind Shocks* are the most likely explanation for the X-ray lines but *magnetically confined plasma* seems to be at the base of the winds.

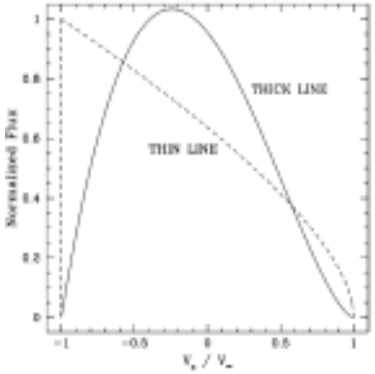
Our Main Diagnostics

- 1. Helium-like ion forbidden, intercombination, & resonance (fir) lines.

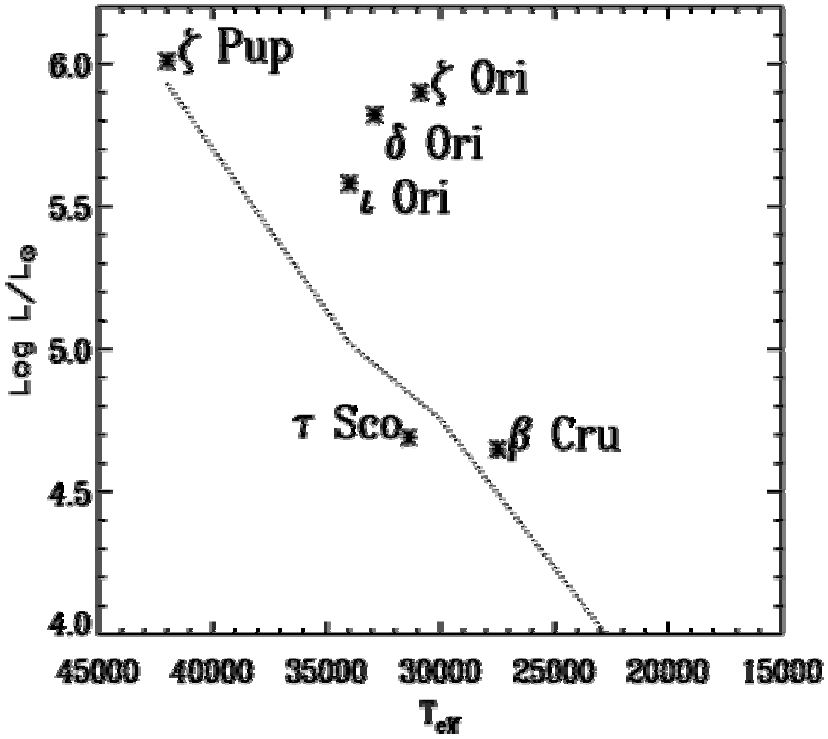


→ **Get the distance of source from star & info on the plasma temperature**

- 2. Resolved spectral line profiles.

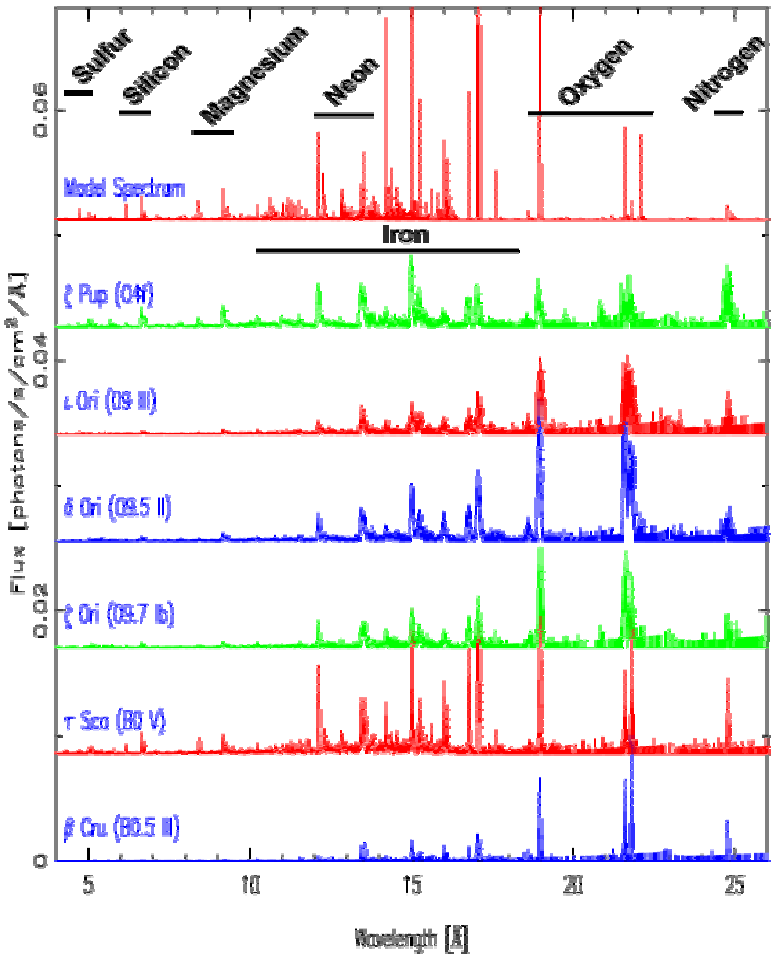


→ **Get info on the source speeds**

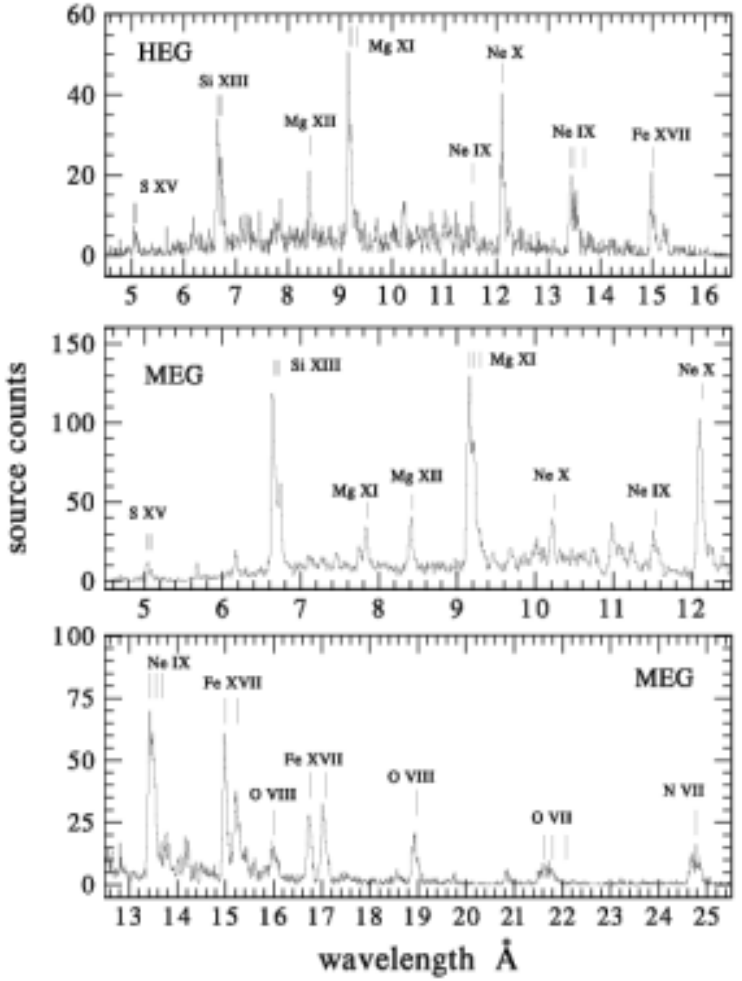


Hot Stars on HR Diagram with Chandra Spectra

Chandra High-Resolution Spectra of 6 stars.



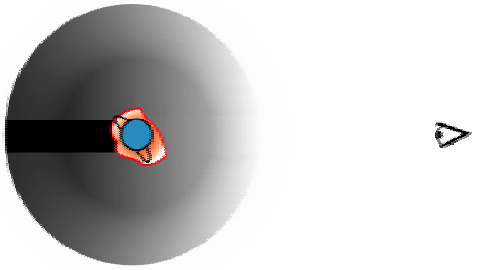
ζ Pup Line Spectrum



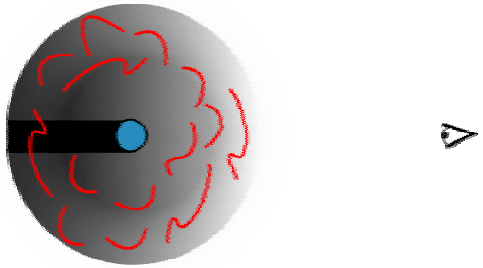
ζ Ori Line spectrum

Source Location: Corona? *or*
Shock Fragments?

Coronal Model:



Distributed Wind **Shock Model**:



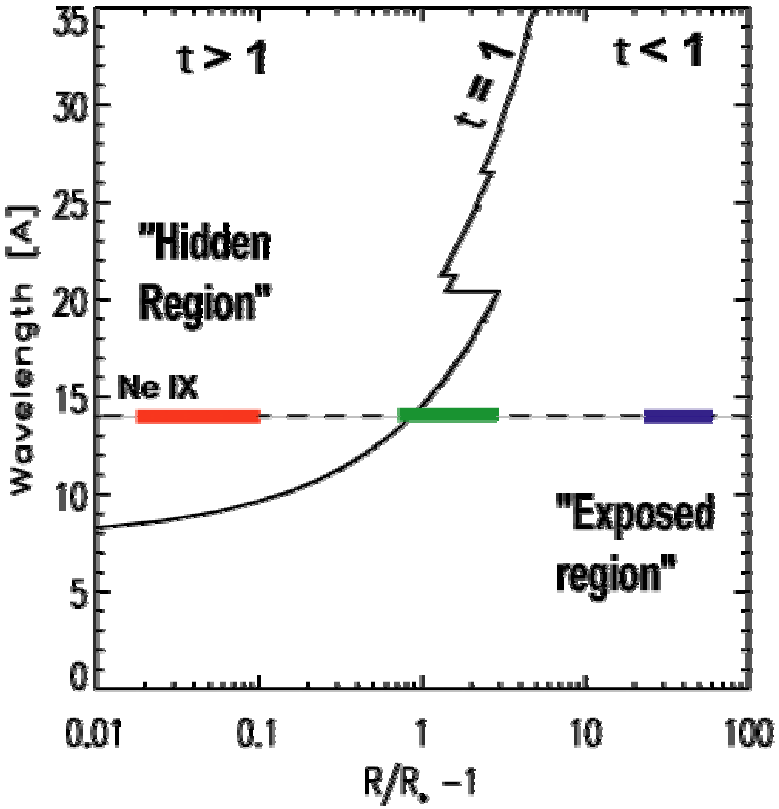
Some constraints for O stars.

1) O Star Winds are Thick at $\lambda > 8$ A

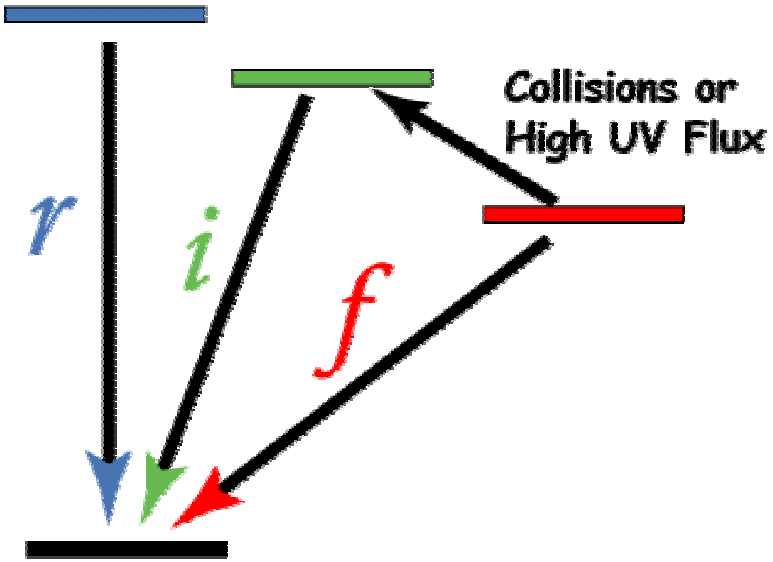
2) Don't see base!? except at short λ *or*
for BV stars such as τ Sco B0.5 V

Source Location Information # 1.

The Radius of Optical Depth Unity



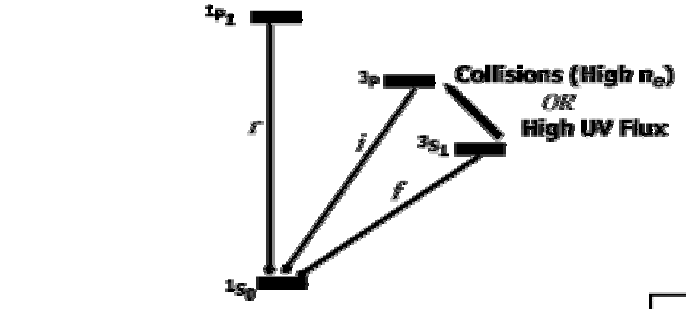
Source Location Information # 2.

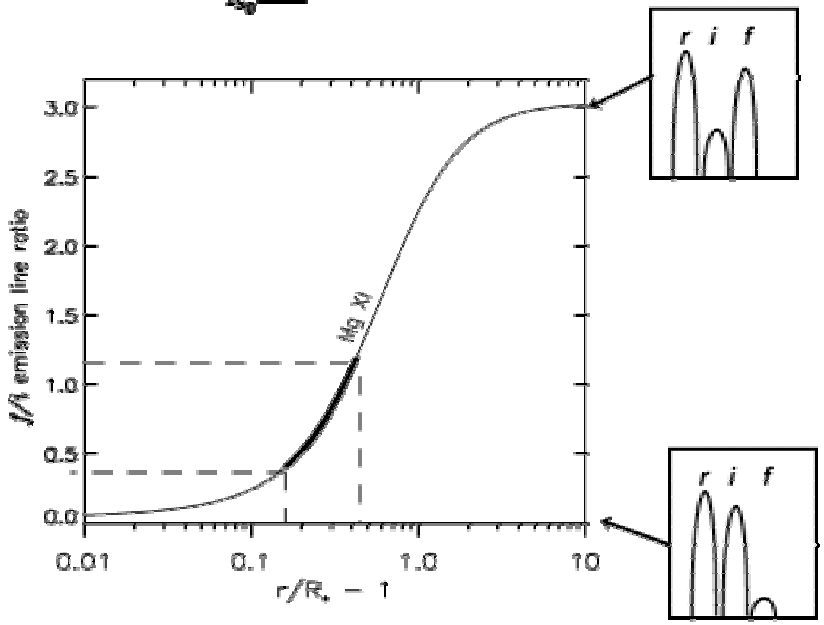


Helium-Like Ions

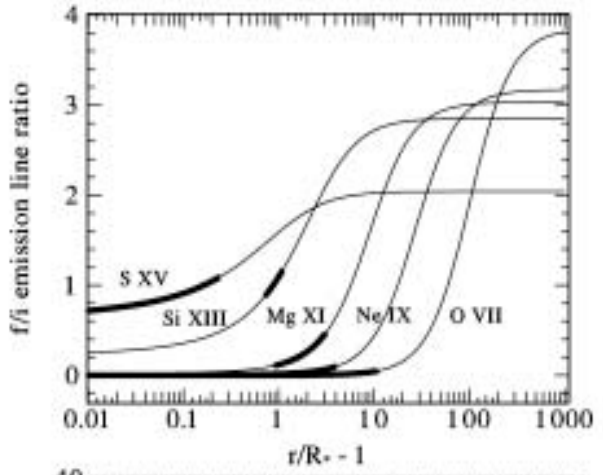
For hot stars, as the source radius increases, f/i ratio also increases

Using He-like Ions to Determine the Location of the Hot Plasma

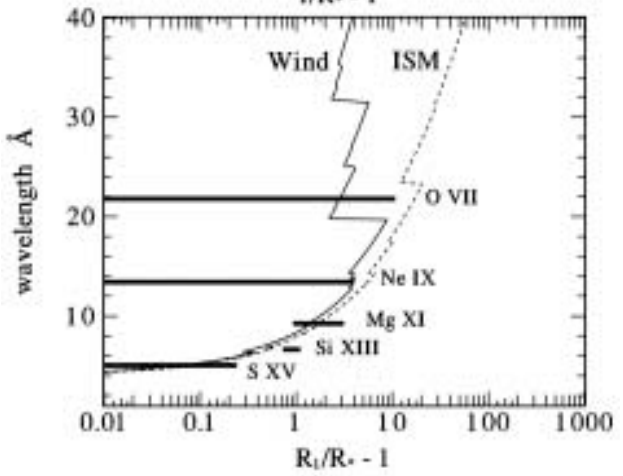




ζ Pup O4f

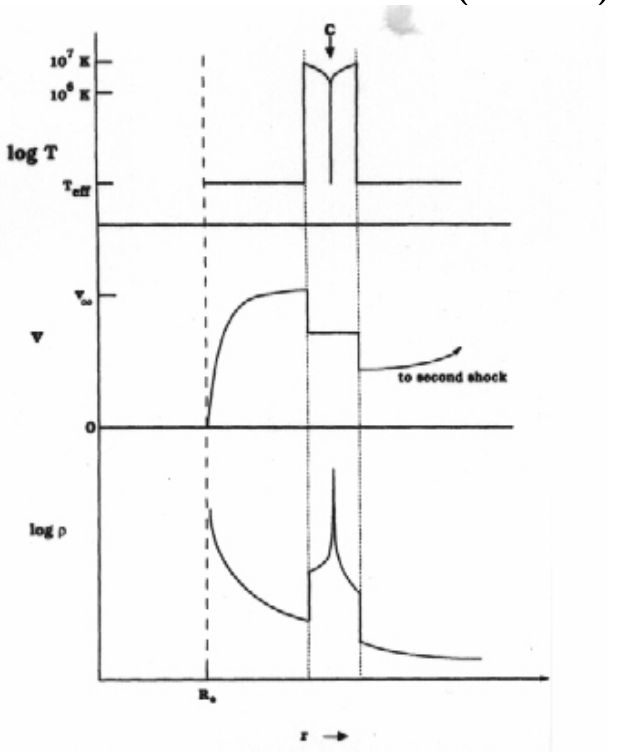


Line Source locations



X-rays form at all depths
but high ions SXV, Si XIII
form very close to Photosphere

Basic wind shock
MacFarlane et al. (1991)

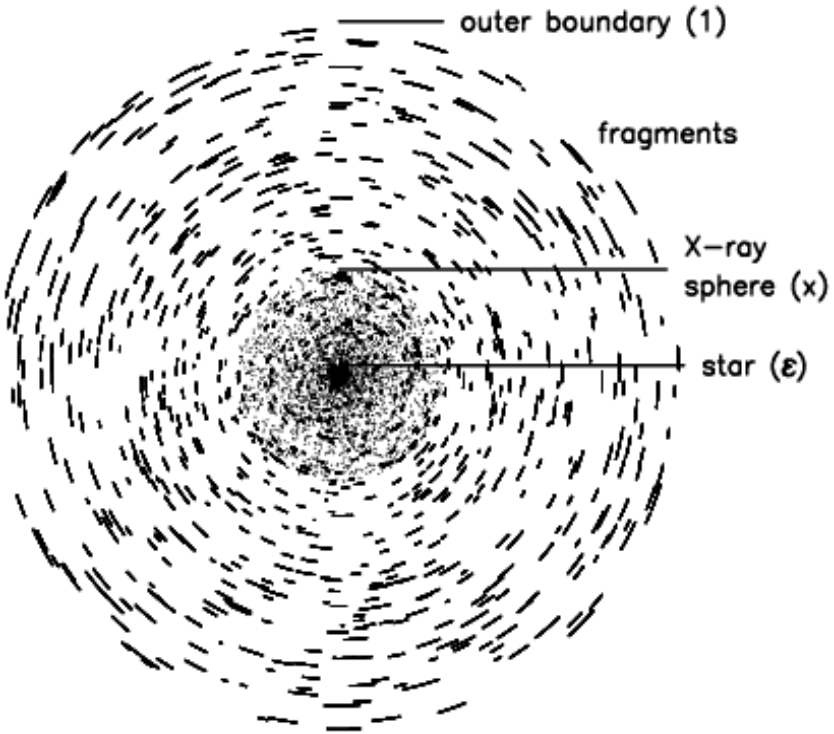


Simple spherically symmetric shocks have two problems. They lead to

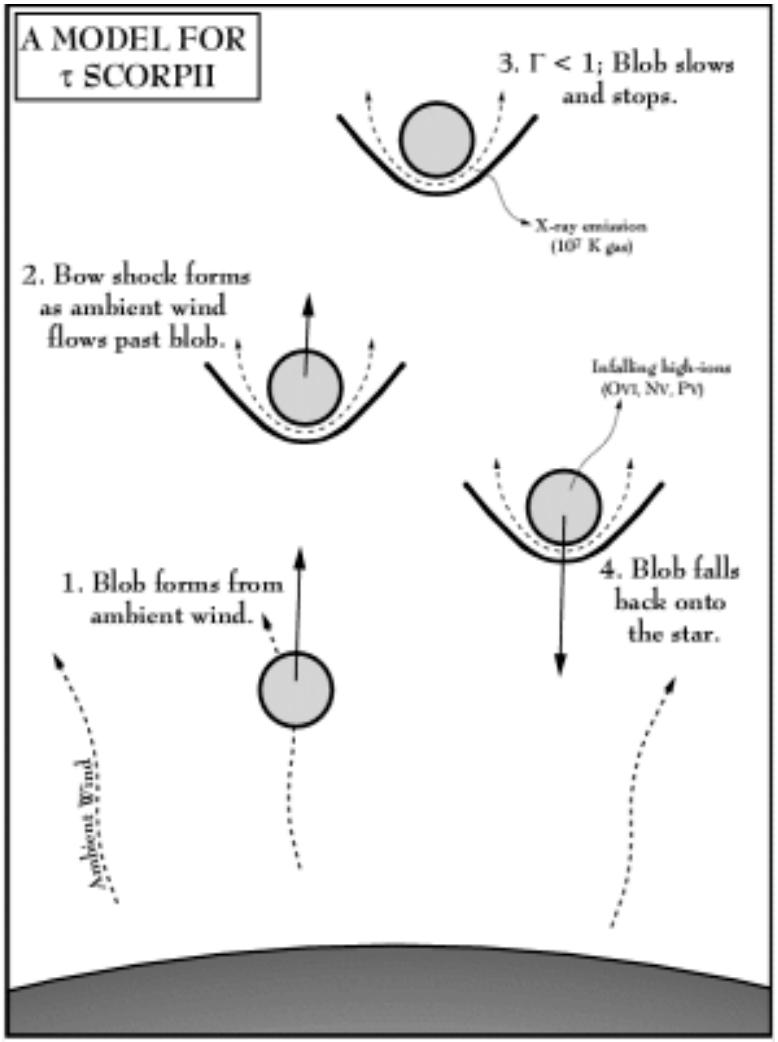
a) too many X-rays and

b) too much time variability

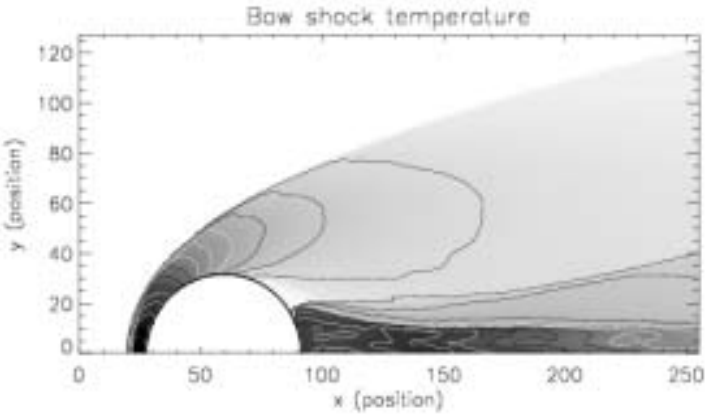
“Shock fragments”



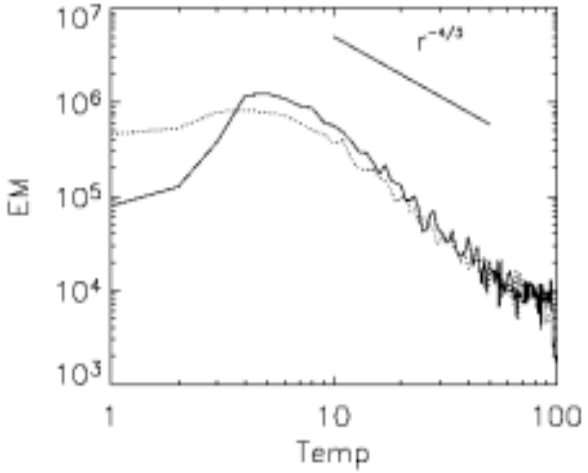
Feldmeier et al. 2002



Howk et al (2000)

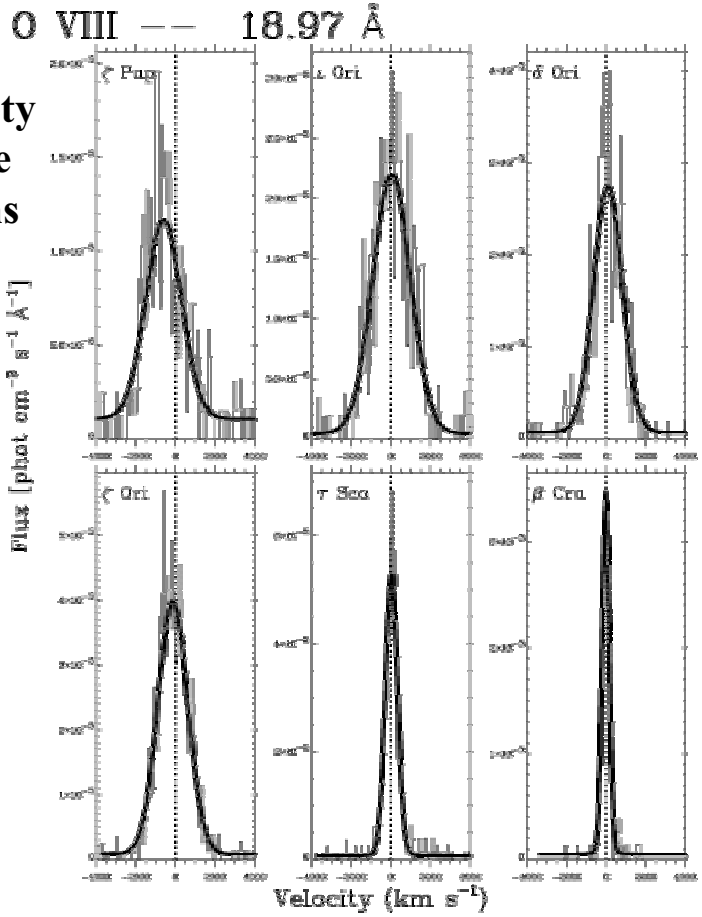


Bow Shock T structure and EM distribution



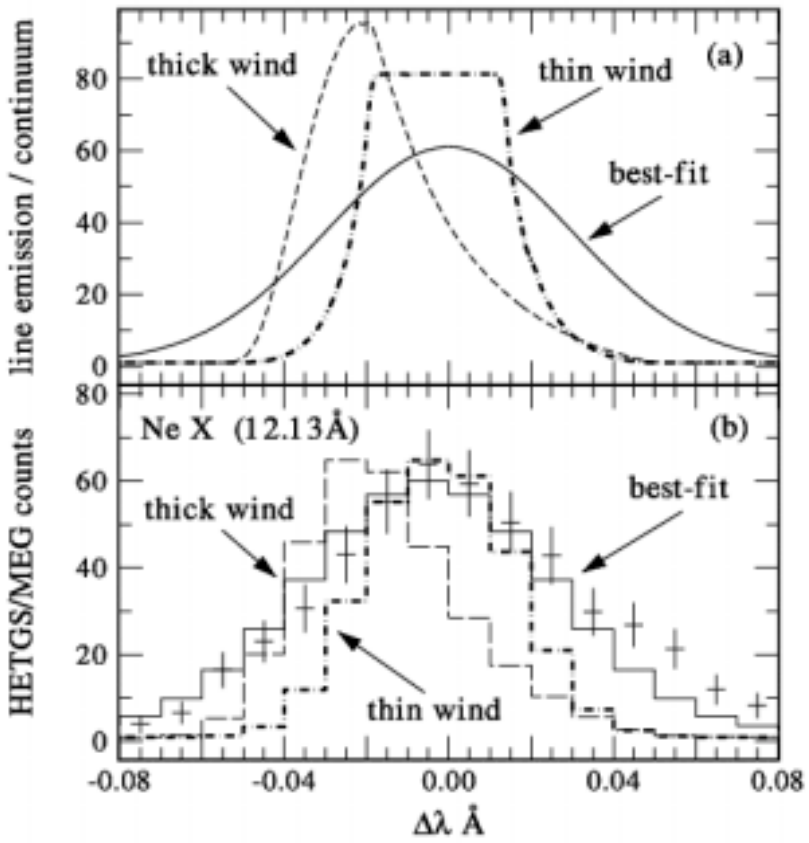
II. Line profiles

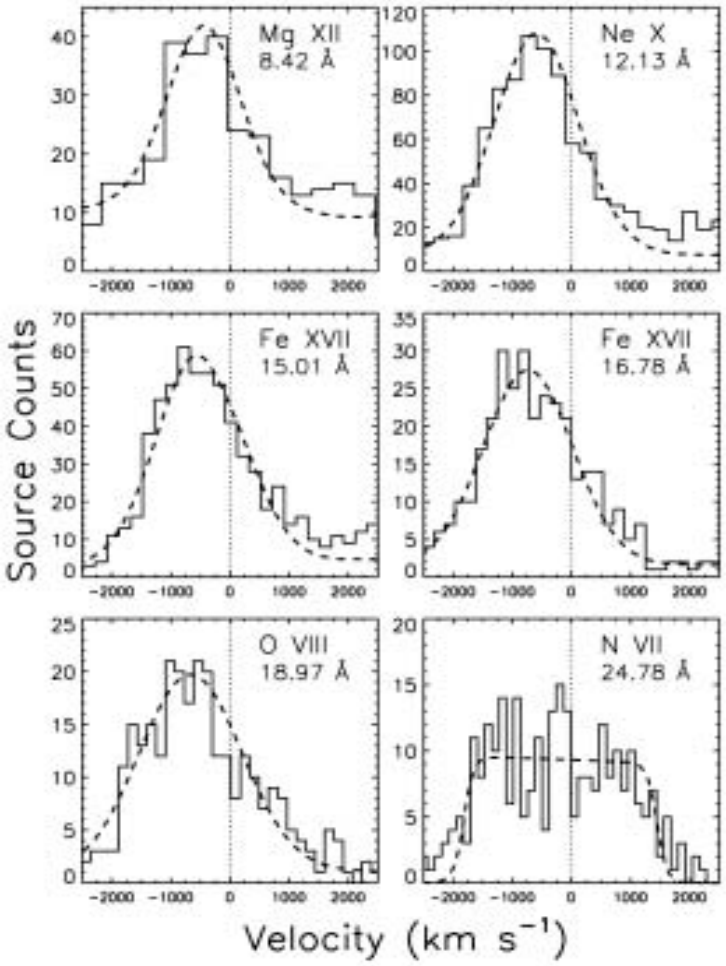
Variety of line widths



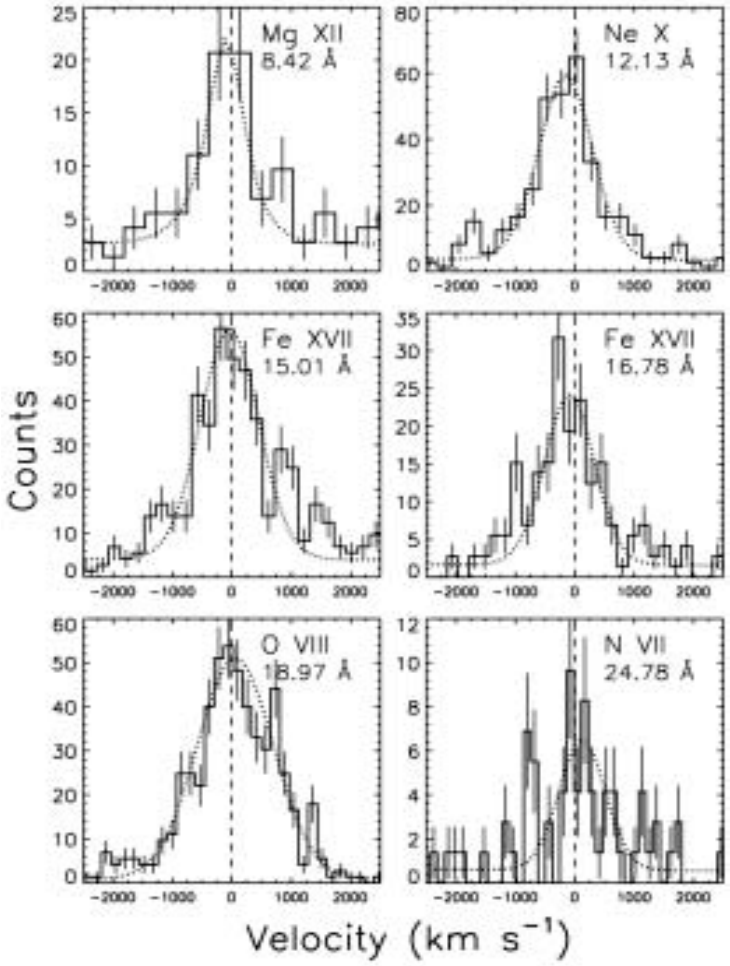
OVIII lines

Predicted versus observed profiles



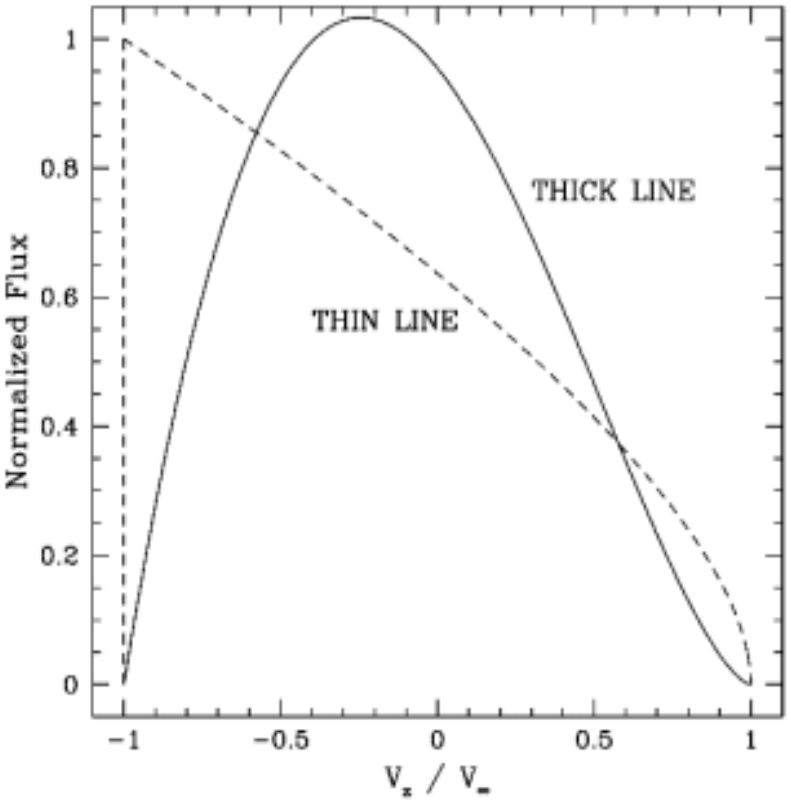


Zeta Pup Lines Blueshift Visible

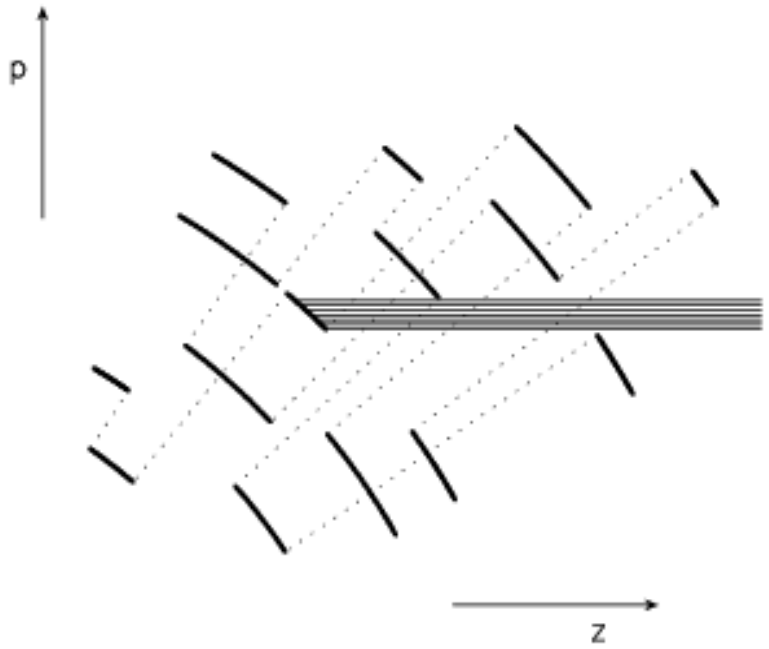


δ Ori, NO obvious shift

Profile fitting (Ignace, Gayley 2002)



Photon escape, *fragmented* shock or *bow* shock models



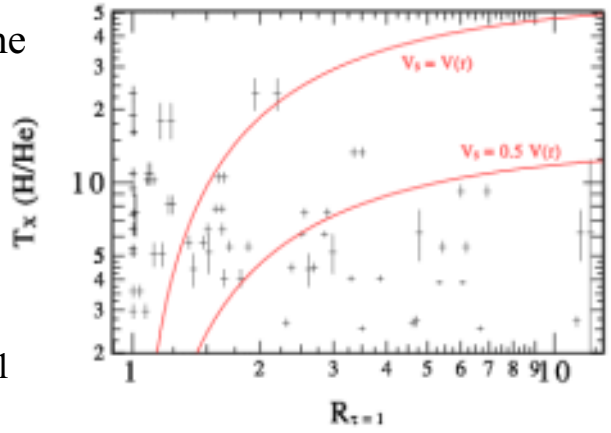
• Escape channels allow us to see deep into the wind, to get more symmetric line profiles, and to see near the base.

Temperature versus radius

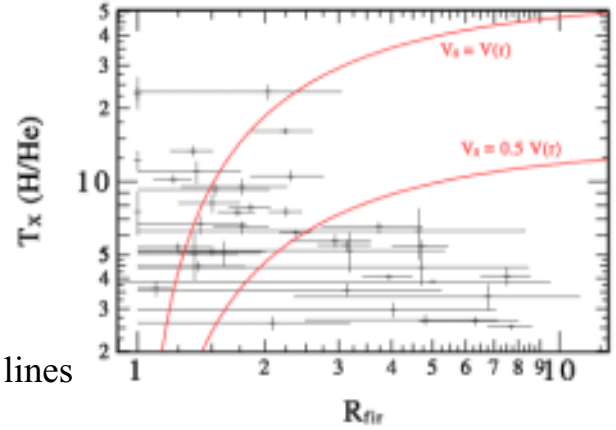
Waldron (2003)

T from the He/H line ratio

R from τ=1



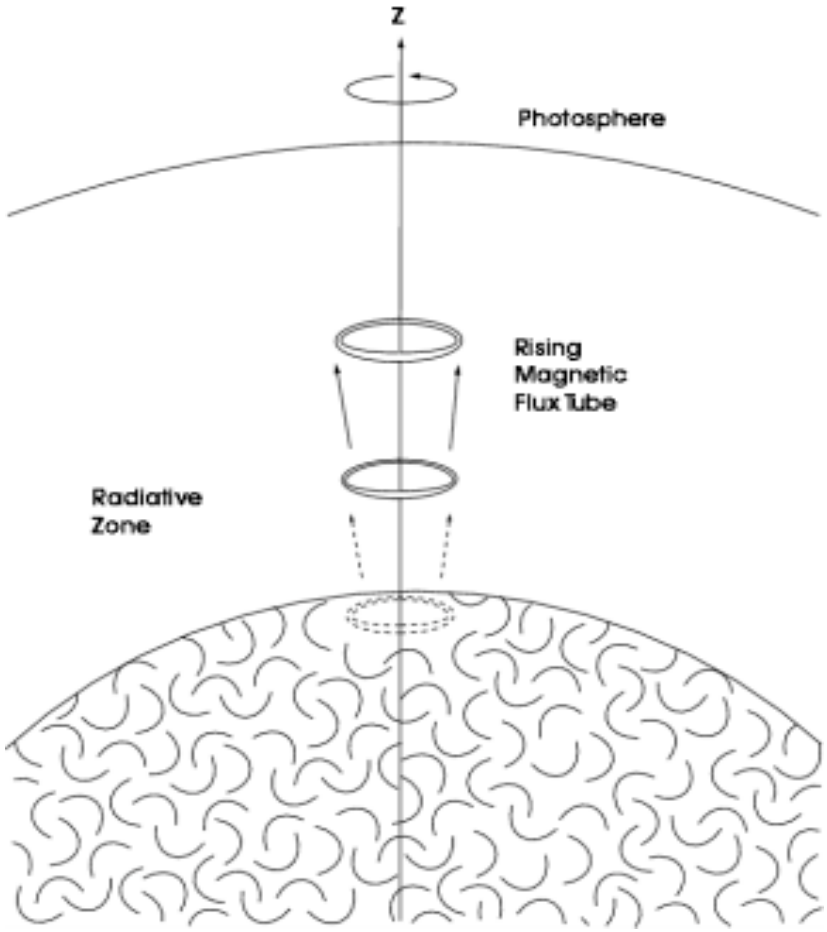
R from fir lines



1) T_{shock} requires excessive Δv jump

2) T_{shock} decreases with Radius

Buoyant Flux Tubes in Hot stars, MacGregor and Cassinelli 2003



Summary

- About 10 OB stars mostly with thick winds observed at highest spectral resolution
- Broad line widths suggest shocks, ***but*** only ζ Pup (O4f) shows the expected blueward-skewed profiles.
- Bow shocks can provide high T's and EM = $T^{-4/3}$, and τ Sco (B0.5 V),
- Fragmentation could reduce the depths, τ_λ,
- B fields on O stars are 'allowed', and could explain high ions, but the X-rays need to penetrate the thick wind, so the line symmetry problem would not be solved by B loops.
- Shock models are not explaining the high Temperatures very near the stars.